Top BSM at DØ

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for the DØ collaboration

Introduction and Outline

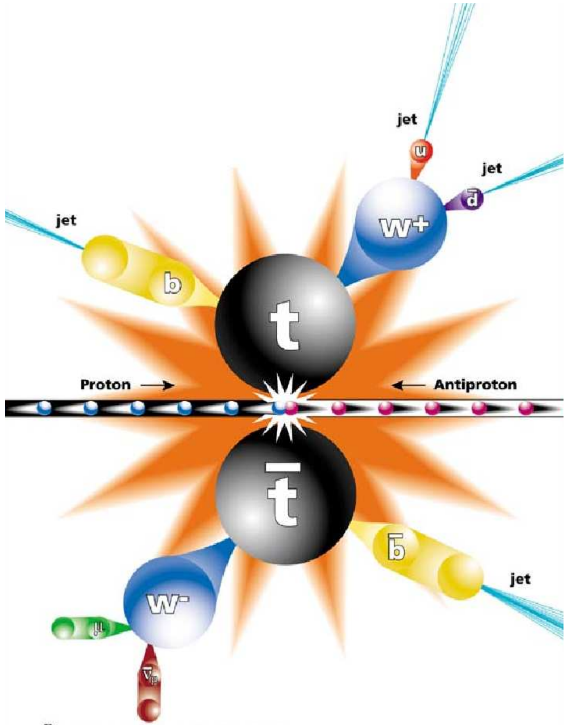
We can question the SM-likeness of the top quark in several ways:

a) Is it the really (to 100%) the top that we see?

b) Is it decaying (to 100%) as expected in SM?

c) Does it have the expected quantum numbers?

d) Is it produced (to 100%) by SM mechanisms?



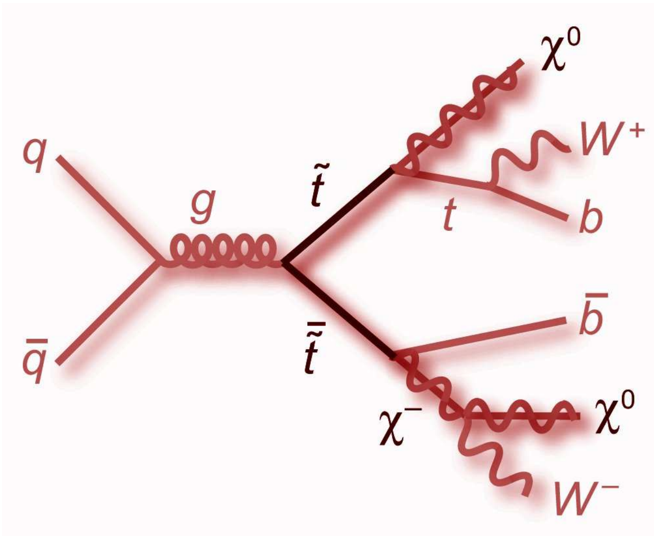
This talk covers one analysis for each of these questions.

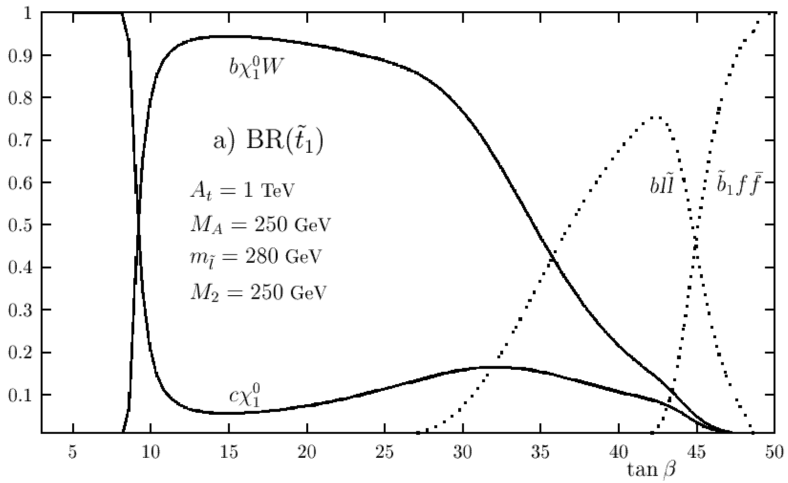
Is it the really the top quark?

Stop Pair Production

Are we really looking at top quarks only?

- An admixture of particles with similar signature might have gone unnoticed
- Stop, $\tilde{t}$, is such a candidate
- Decays: $\tilde{t}_1 \to \tilde{\chi}_1^0 t \to \chi_1^0 bW$
  $\tilde{t}_1 \to \tilde{\chi}_1^+ b \to \chi_1^0 bW$
- Decays similar to top-quarks can dominate over a large range of $\tan\beta$
- Assumptions: $m_{\tilde{t}} \leq m_t$;
  $m_{\chi^\pm}$ and m_{χ^0} close to exp. limits





Signature

Signature of the considered $\tilde{t}\bar{\tilde{t}}$ production is very similar to SM $t\bar{t}$ production

ℓ+jets channel considered

High p_T Lepton, $\not{E}_T$ from χ^0 and ν, jets from 2 b quarks and 2 light quarks

Dataset and Background Description

- Selection as cross-section (Iso. electron or muon, $\not{E}_T$, ≥ 4jets, ≥ 1 b-tag)
- Until now $\sim 0.9\,\text{fb}^{-1}$ analysed
- Background description
  - $t\bar{t}$, and further, minor backgrounds : MC normalised to theroy.
  - W+jets normalisation from data (Matrix Method), kinematics from MC
  - Multijet from data (Matrix Method)
- Signal MC is generated for a variety of Stop/Chargino masses.

Likelihood (I)

To distinguish top pair from stop pair production a likelihood is constructed

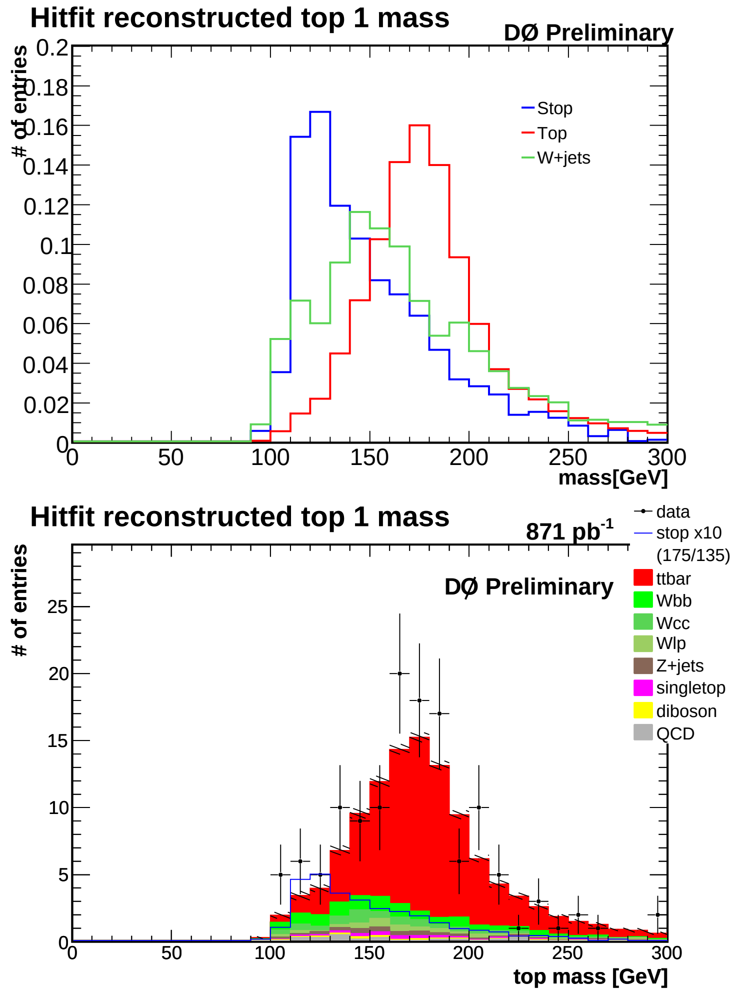
Constraint fit to construct add. observables

Constraint Fit

Reconstruct as if top pair event:

- $m_{qq} = M_W$, $m_{\ell\nu} = M_W$, $m_t^{(1)} = m_t^{(2)}$
- Jet-parton assignment by best χ^2
  b-tagged jets assigned to b-quarks only
- Inputs to likelihood:
  - m_t, $\cos\theta^*(b,b)$ $m(b,b)$,
    $\Delta R(W, b_{\mathrm{samechain}})$, $\Delta R(W, b_{\mathrm{otherchain}})$

Plots show m_t for data and simulation



$m_{\tilde{t}} = 175$ GeV, $m_{\chi^\pm} = 135$ GeV

Likelihood (II)

Kinematic variables

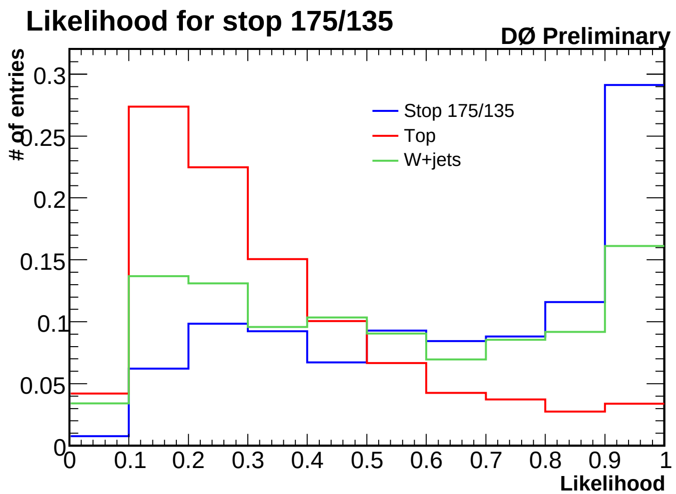
- p_t leading b-jet, $M_T(W_\ell)$, $K_{T,\min}$, $m(j_3, j_4)$, $\Delta R(b\text{-jet}, \text{leading other jet})$, $\Delta R(\ell, b)$

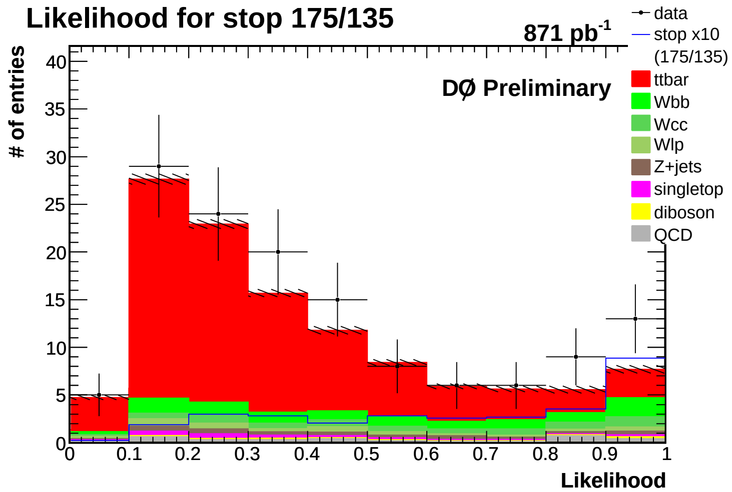
Construction

- Signal and bkg. prob. densities $P(x)$ built from expected distributions.
- $\mathcal{L}(x) = \dfrac{P_{\text{sig}}(x)}{P_{\text{sig}}(x) + P_{\text{bkg}}(x)}$

  $\mathcal{L}$ separates stop signal from bkg.
- Choice of input vars optimised per $m_{\tilde{t}}$, $m_{\chi^\pm}$

Data look quite SM like



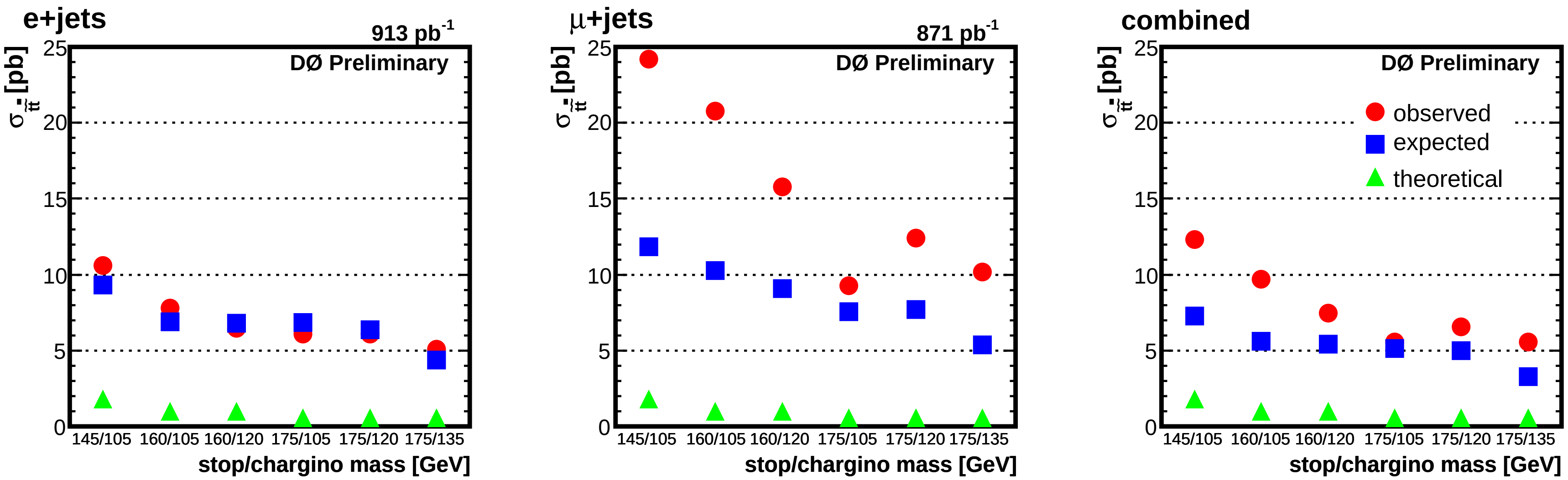


$m_{\tilde{t}} = 175$ GeV, $m_{\chi^\pm} = 135$ GeV

Results

We set limits on cross-section for various $m_{\tilde{t}}$,$m_{\chi^\pm}$:

- Bayesian approach with flat prior in $\sigma_{\tilde{t}\bar{\tilde{t}}}$
- Systematics considered by fluctuating the Poisson parameter of the prob.df
  - $t\bar{t}$ normalisation (incl. m_t dependency), Selection eff, Luminosity, ...

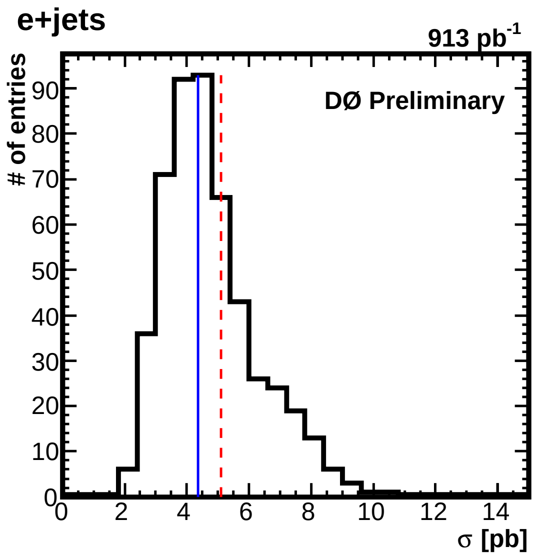


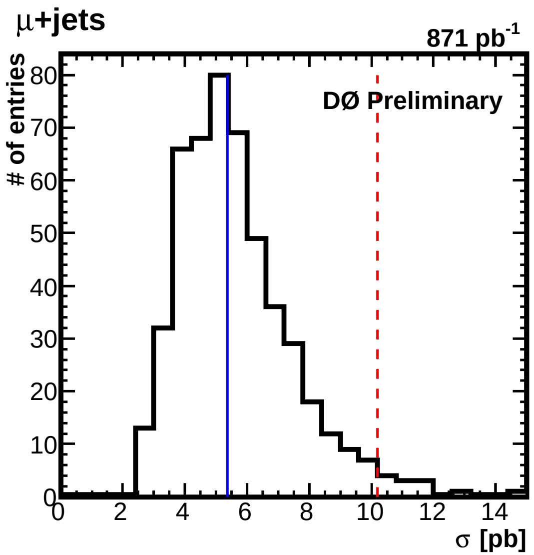
- Simultaneous determination of $\sigma_{\tilde{t}\bar{\tilde{t}}}$ and $\sigma_{t\bar{t}}$ yields very similar results

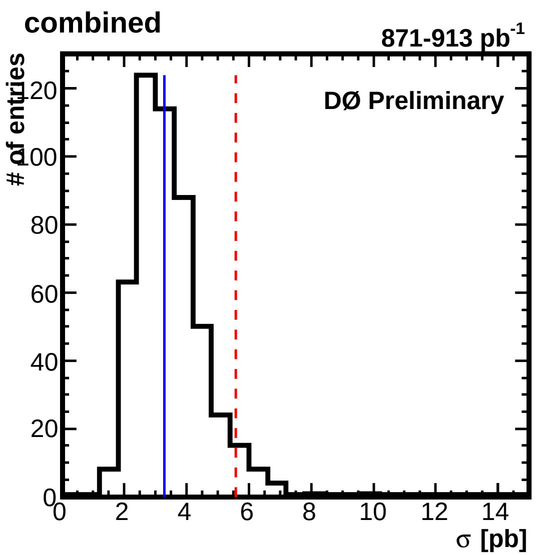
Cross-check with Ensemble Tests

Observed limits much larger than expected ones

- 500 pseudo results were produced for SM phyiscs
- Distribution of results reveals large tails towards high value limits
- Some percent of ensembles worse that μ+jets channel





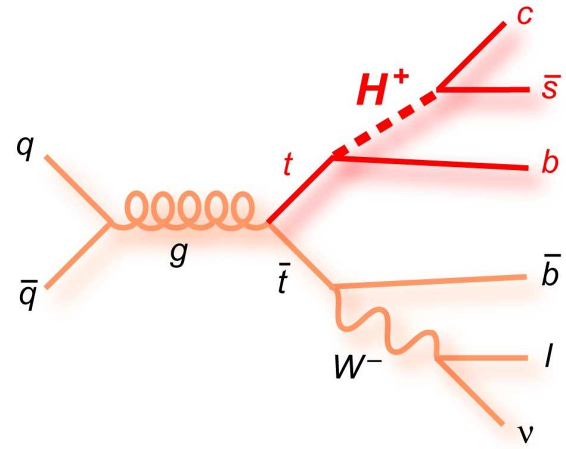


Result can be interpreted as SM fluctuation

Is it decaying as expected?

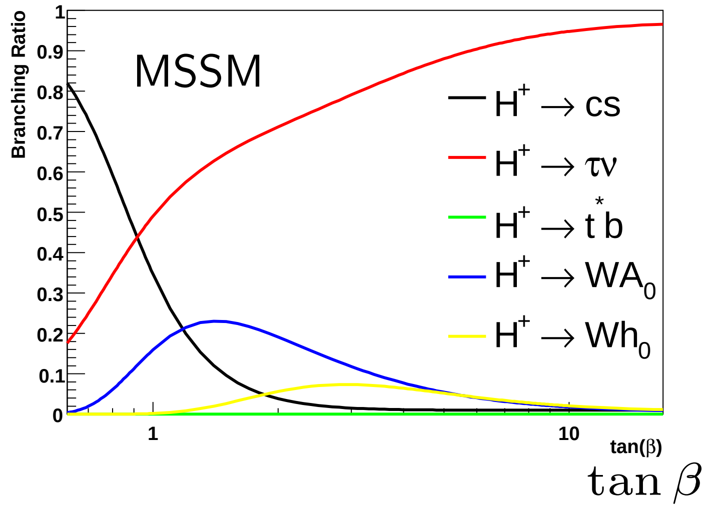
Non-standard decay mode

New particles in the final state alter deduced $\sigma_{t\bar{t}}$ depending on decay channel $C = \ell$+jets, Dilepton



$$\sigma_{t\bar{t}}^{C} = \sigma_{t\bar{t}} \cdot \frac{B^{\mathrm{BSM}}(t\bar{t} \to C)}{B^{\mathrm{SM}}(t\bar{t} \to C)}$$

- Check cross-section ratio $R_\sigma = \dfrac{\sigma_{t\bar{t}}^{\ell+\mathrm{jets}}}{\sigma_{t\bar{t}}^{\mathrm{Dilepton}}}$
- Consider decay $t \to bH^\pm$ with $H^\pm \to cs$
- i.e. leptophobic charged Higgs



Within MSSM relevant only at low $\tan\beta$

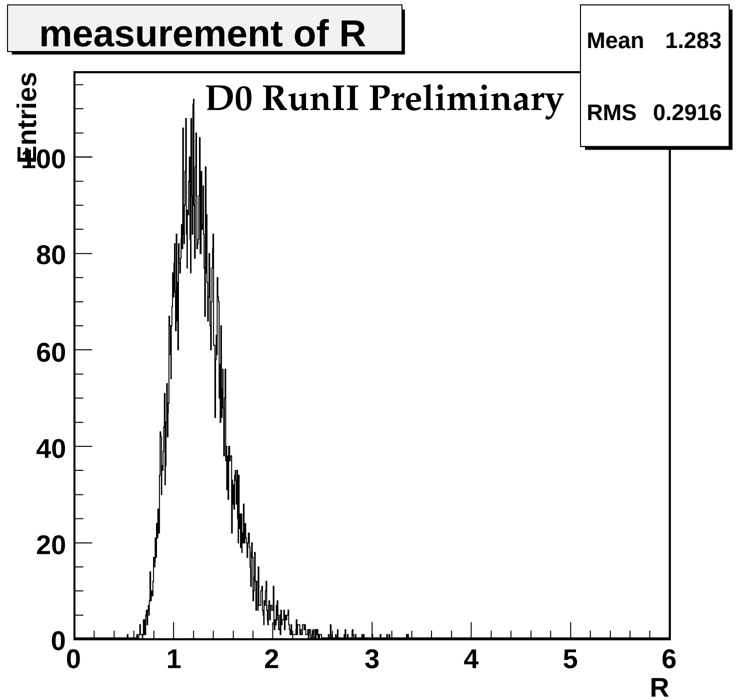
General multi-Higgs-doublet models allow such leptophobic charged Higgs

Determination of Cross Section Ratio

Utilise $\sim 0.9\,\mathrm{fb}^{-1}$ (ℓ+jets) and $\sim 1.0\,\mathrm{fb}^{-1}$ (Dilepton)

Important: treat correlations correctly

- Fully correlated:
  - Lepton and Primary vertex ID
  - Muon trigger
  - JES, JER, JetID
  - Diboson normalisation
- Lumi uncertainty cancels in ratio
- Remaining: uncorrelated



Implemented combined ensemble testing.

- Draw event number according to Poisson statistics
- Vary expectation parameters according to systematics correlated/uncorrelated

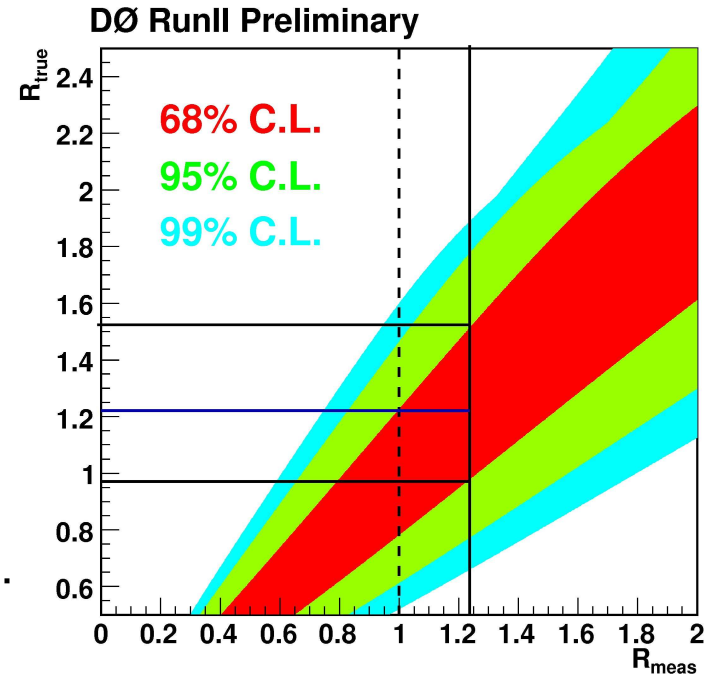
Determination of Cross Section Ratio (II)

Proceedure is repeated for many hyothetical values of R.

- Done by changing $\sigma_{t\bar{t}}^{\ell+\text{jets}}$
- 10000 pseudo results per nominal R_σ
- Fitted to have parametric relation between $R_\sigma^{\text{measured}}$ and $R_\sigma^{\text{nominal}}$

Interpreted using Feldman-Cousins approach:

- Find most likely interval of nominal R_σ that may yield observed value.
- Add points according to max. likelihood ratio.
- 68% confidence intervall of $R_\sigma^{\text{nominal}}$:



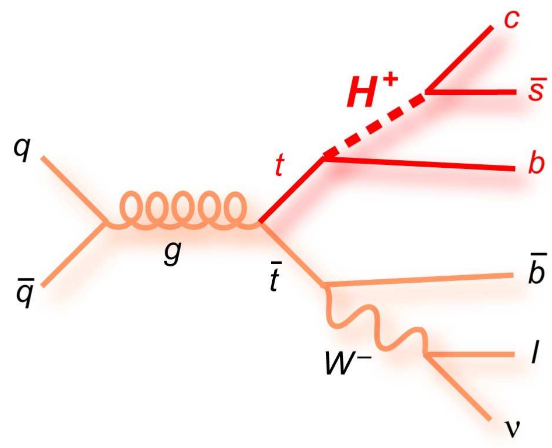
$$R_\sigma = 1.21 \pm 0.27\,\text{pb}$$

Top Branching Ratio to $H^\pm$

Assuming $H^\pm \to cs$ to 100%:

- Dilepton: both tops need to decay through W
- ℓ+jets: only one or both may decay through W

$\Rightarrow$ Ratio: $R_\sigma = 1 + \dfrac{x}{(1-x)B(W \to qq)}$

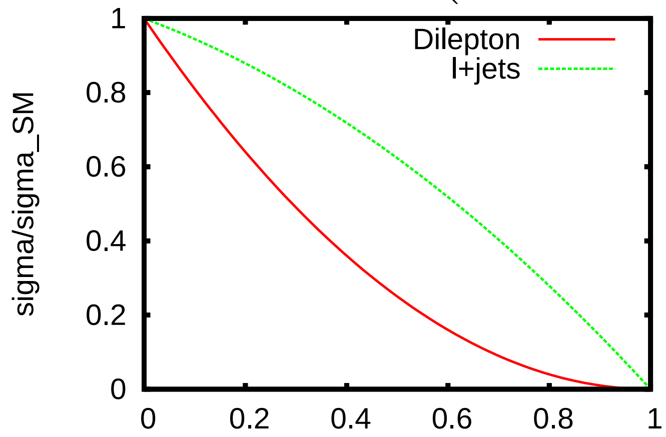


- Formula is extended to account for leakage between the channels.

$B(t \to bH^\pm)$ is deduced as R_σ before.

- Pseudo results (ensembles) created with proper systematic variation
- Functional form fitted
- Interpreted using Feldman-Cousins approach.

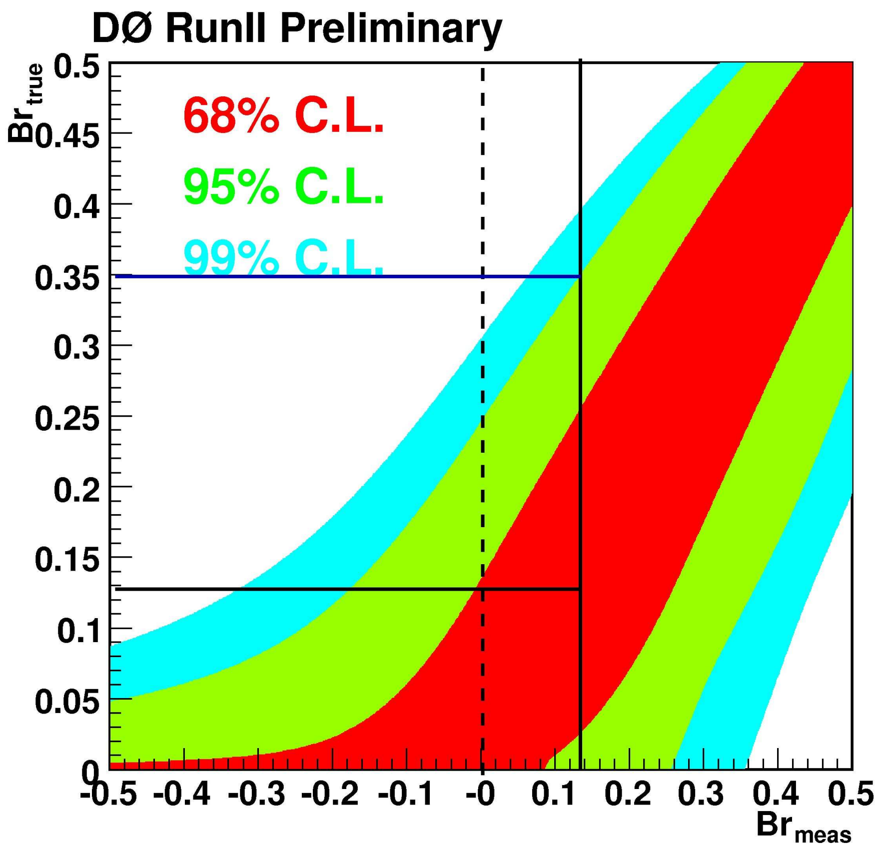
$x := B(t \to bH^\pm)$



Top Branching Ratio to $H^{\pm}$

For a 80 GeV charged Higgs decaying only hadronically we find

- Expected limit within SM:
  $B(t \to bH^{\pm}) < 0.25$ (95%CL)

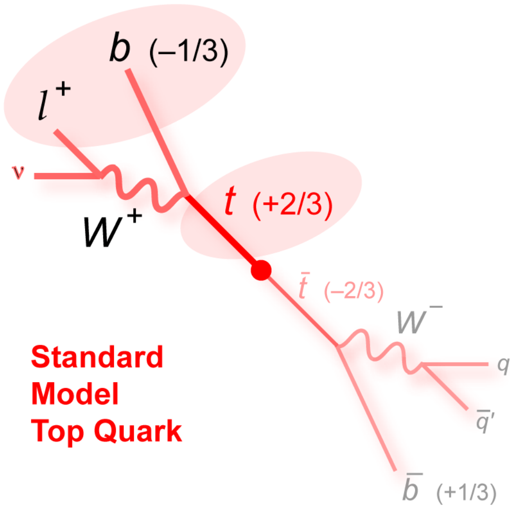


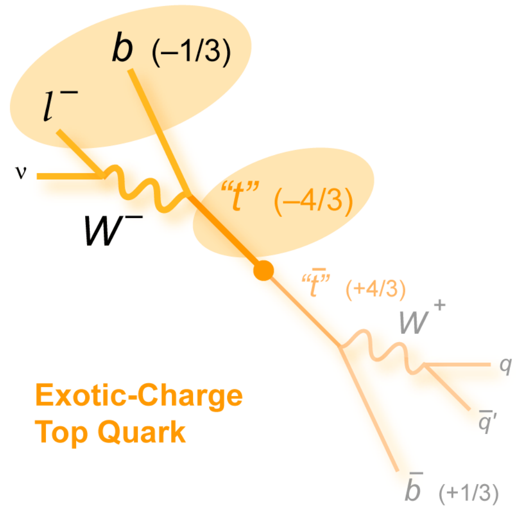
$B(t \to bH^{\pm}) = 0.13 \pm 0.12$ $\qquad$ $B(t \to bH^{\pm}) < 0.35$ (95%CL)

Does it have the expected quantum numbers?

Top Quarks Electrical Charge

Do objects used to reconstruct tops add up to the expected charge?





Requires reconstruction of:

- W charge $\Longrightarrow$ lepton charge
- b-quark charge $\Longrightarrow$ jet charge (more involved)

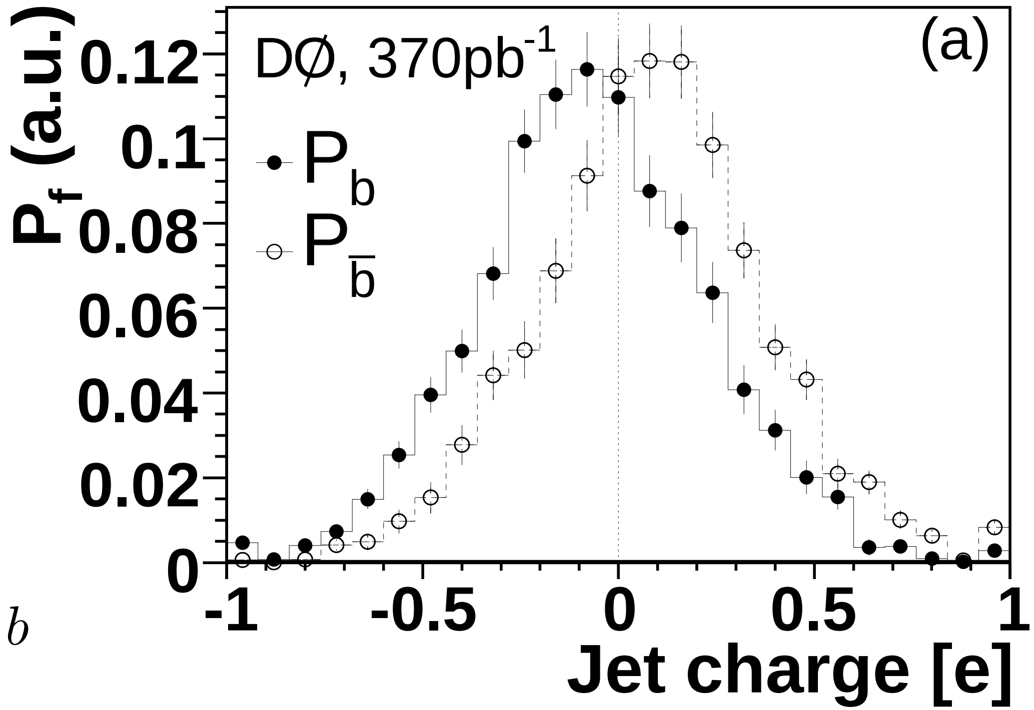
Performed in ℓ+jets channel with $370\,\text{pb}^{-1}$

Jet charge

Sum charge of tracks in b-jet

- Errors from in- and out-of-cone tracks
- Statistical method
- Weighting with p_T helps

$$Q_{\text{jet}} := \frac{\sum q_i \cdot p_{Ti}^{0.6}}{\sum p_{Ti}^{0.6}}$$



b

Calibration

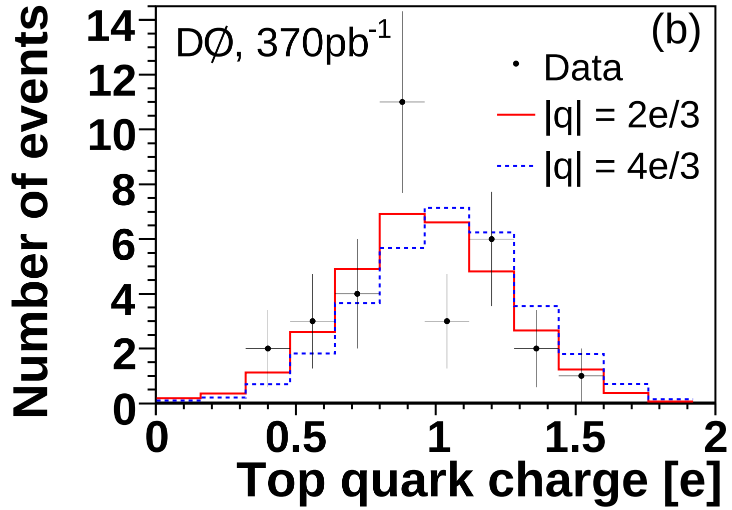
- Using double (vertex) tagged $b\bar{b}$ dijets w/ soft μ ($\Delta\phi \leq 3.0$)
- Soft μ determines b charge, Q_{Jet} calibrated on opposite jet.
- Disentangle b, $\bar{b}$, c, $\bar{c}$ contributions to obtain pure b-jet Q_{Jet} distribution

Top Quark Charge Analysis

- Need to assign b-jet to right top
  Choose best fit to top hypothesis
- Combine lepton and b-jet charge to top charge (leptonic and hadronic side):

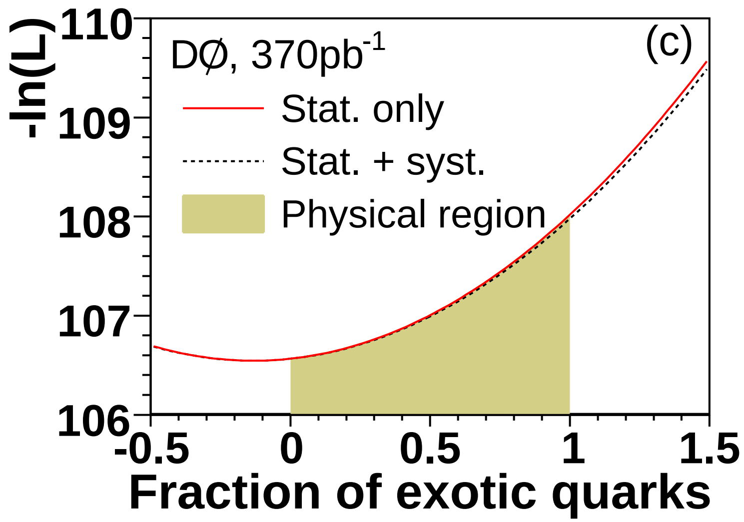
$$Q_{\text{lep}} = \left|q_l + q_{b_\text{l}}\right|$$
$$Q_{\text{had}} = \left|-q_l + q_{b_\text{h}}\right|$$

- Templates generated from standard model MC.
  Exotic case by permuting jet charge.



DØ Result ($370\,\mathbf{pb}^{-1}$)

Unbinned likelihood ratio also accouting for remaining background yields



p-value for $|q_{\text{top}}| = 4e/3$ is 7.8%.
Bayes factor is 4.3.

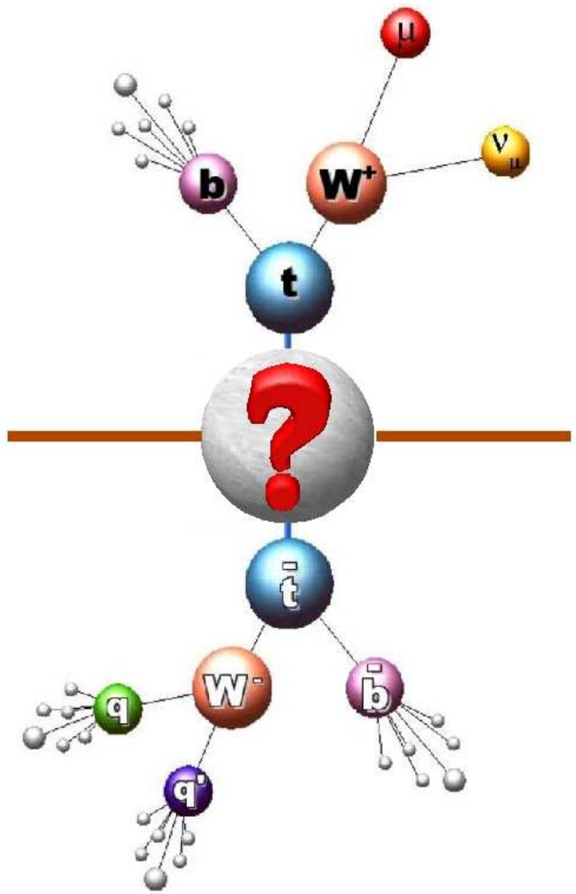
Is it produced by SM mechanisms only?

Resonant Production of Top Pairs

No resonance production in $t\bar{t}$ expected in SM,

but some models predict bound $t\bar{t}$-states

- new strong gauge force coupling to 3rd generation
- top-color assisted technicolor: Z'

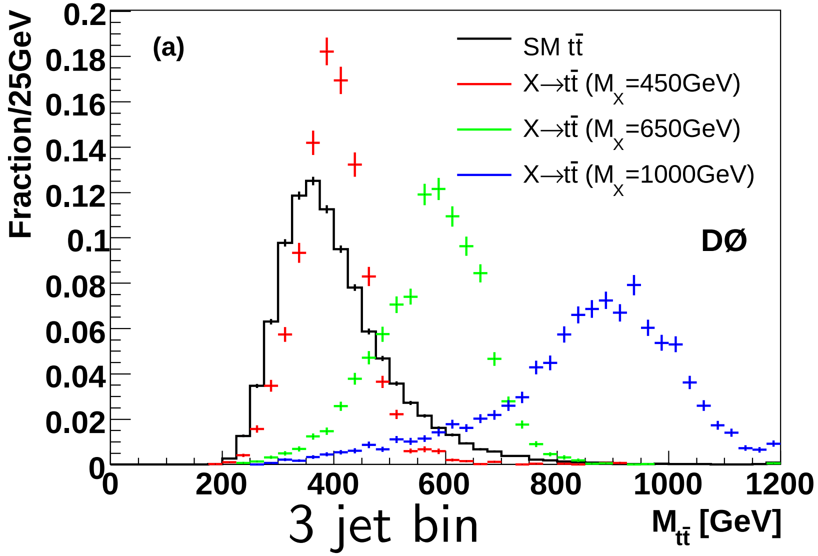


Such a reasonance should create a bump in differential cross-section $\frac{\mathrm{d}\sigma}{\mathrm{d}m_{t\bar{t}}}$

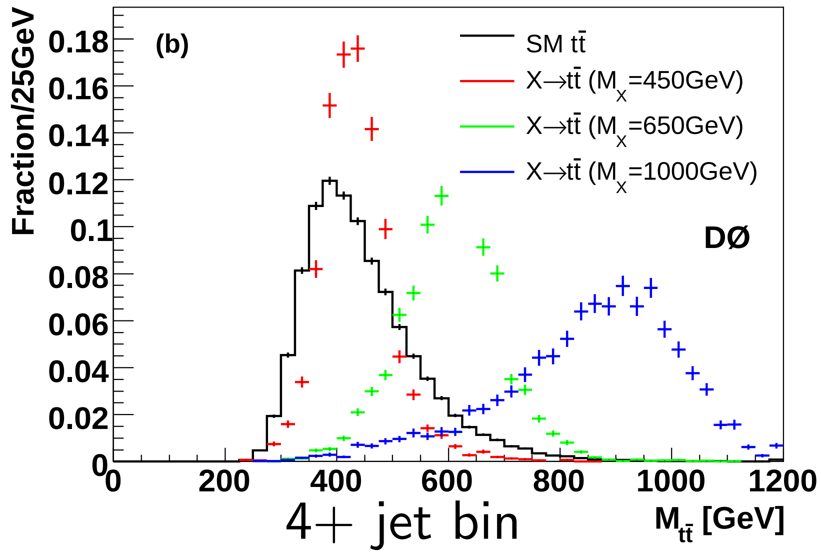
Assume its width is smaller than detector mass resolution

Reconstruction of Invariant Mass of $t\bar{t}$

- Reconstruct $m_{t\bar{t}}$ directly from ℓ, ν and up to 4 leading jets (no constraint fit)
- Neutrino: p_x, p_y components from $\not\!\!E_T$ and p_z^ν from $M_W^2 = (p^\nu + p^l)^2$
- Selection as cross-section (Iso. electron or muon, $\not\!\!E_T$, $\geq$ 3jets, ≥ 1 b-tag)



3 jet bin



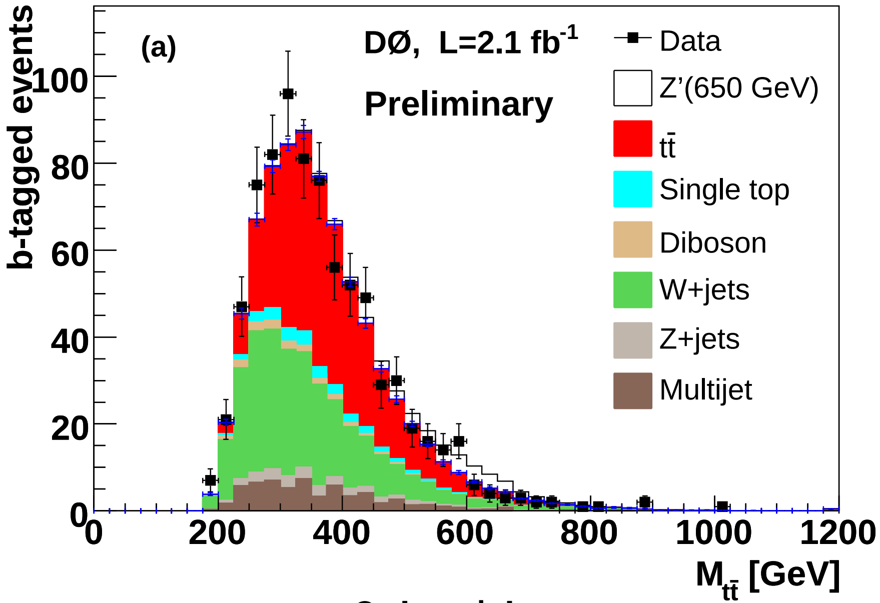
4+ jet bin

- Resonant production shows more narrow $M_{t\bar{t}}$ distributions than SM $t\bar{t}$
- With increasing resonance mass SM background becomes less important.

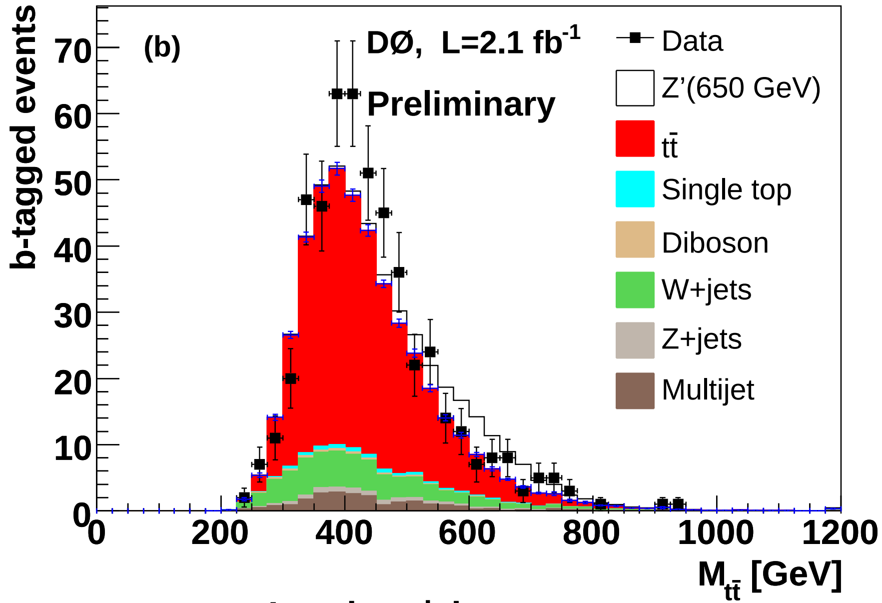
Background Estimation

- $t\bar{t}$, Z+jets, single top quark and diboson: MC normalized to theory.
- W+jets, normalisation from data, shape from Monte Carlo
- Multijet from data only

Top pair invariant mass



3 jet bin



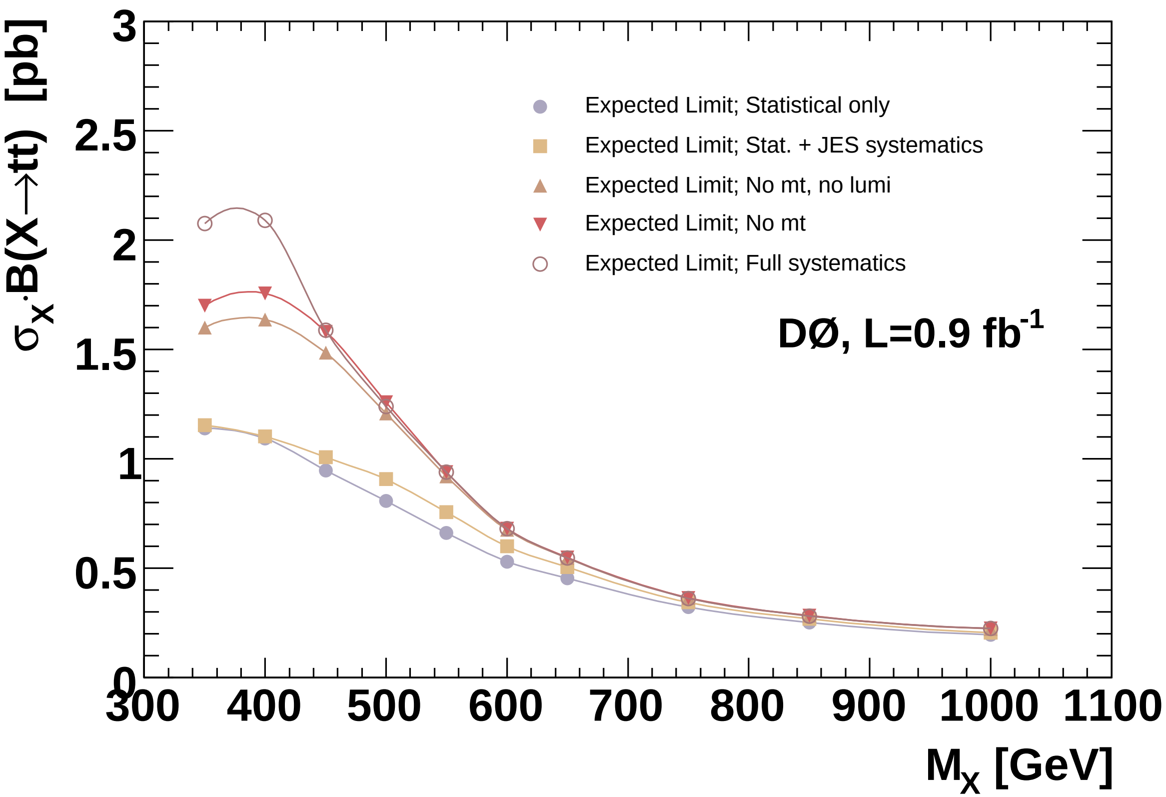
4+ jet bin

Limit calculation

Bayesian statistics is used to determine obtain the results (as for stop)

Systematics (Expected Limits for $0.9\,\mathrm{fb}^{-1}$)

Expected limits are computed by using background prediction as “observation”

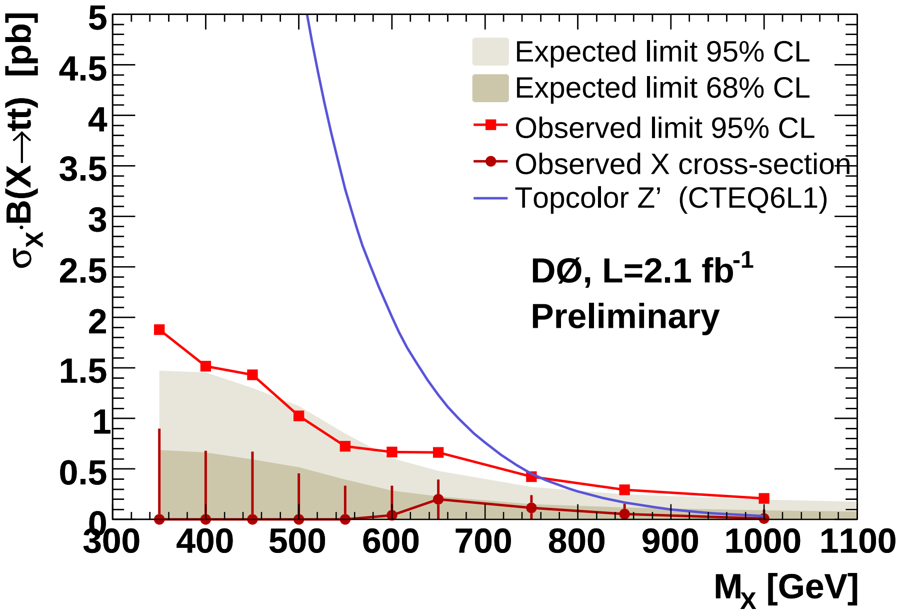


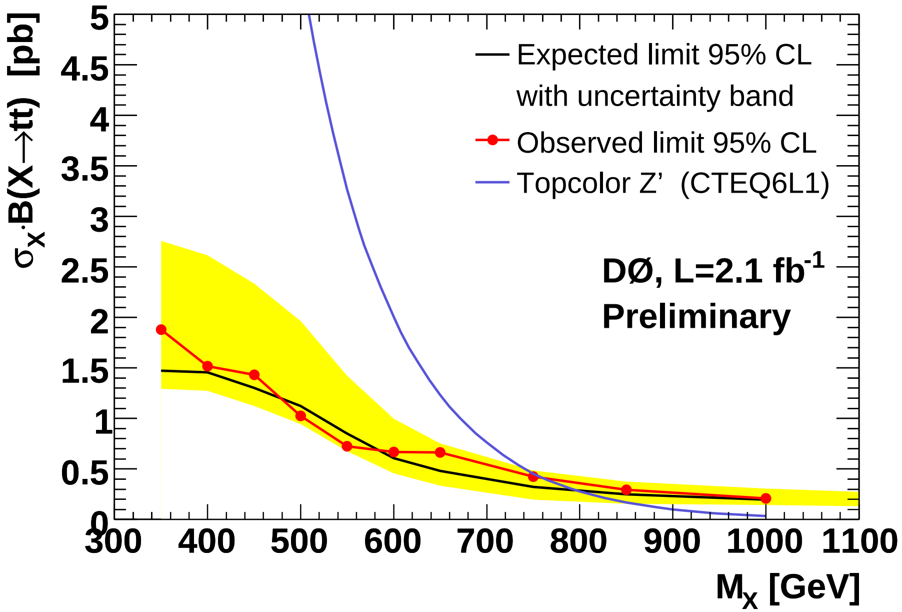
Systematics may just scale the background or change the background shape

- JES affects medium M_X
- Luminosity, efficenies, … scale like bkg shape
- m_t affects low M_X

High M_X stat. dominated

Top Resonance Results ($2.1\,\text{fb}^{-1}$)





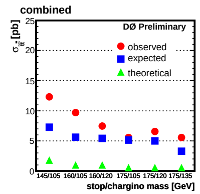
- All measured $\sigma_X \cdot B(X \to t\bar{t})$ close to zero (max. deviation $\sim 1\sigma$)
- Thus we set limits on $\sigma_X \cdot B(X \to t\bar{t})$
- Top-color assisted technicolor Z':

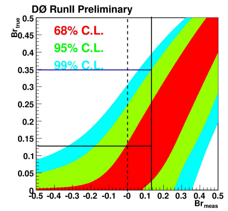
Expected Limit $M_{Z'} > 795\,\text{GeV}$
Observed Limit: $M_{Z'} > 760\,\text{GeV}$

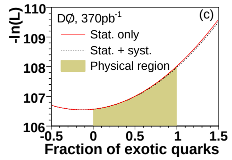
Summary

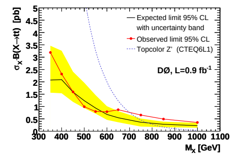
- With increasing Luminosity we get access to more and more BSM phenomena

- DØ has questiond the SM-likeness in various aspects
  - Search for Stop admixture
  - Search for charged Higgs in top decay
  - Check of top electric charge
  - Search for resonant $t\bar{t}$ production









- No deviation from SM was observed, yet.

DØ is working on updates for all these analyses